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Evaluating Fish–Habitat Relationships for Refining Regional Indexes of Biotic Integrity: Development of a Tolerance Index of Habitat Degradation for Maryland Stream Fishes

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Abstract.—I present tolerance values of stream fishes to specific characteristics of habitat quality in an effort to refine mid-Atlantic regional indices of biotic integrity. Species presence and abundance data were examined within ranges of habitat quality variables to reveal normalized habitat tolerance characteristics for 54 species found in nontidal streams of Maryland. Development of a fish habitat tolerance index (FHTI) provided information on the overall susceptibility of individual species to habitat degradation. Designations of intolerant, moderately intolerant, and tolerant were assigned to all species individually and compared across three regional strata (Coastal Plain, Eastern Piedmont, Highlands). Family Cyprinidae (minnows) contributed the five most intolerant species. Omnivores and invertivores contributed the top 10% of species, showing general intolerance to declining habitat quality. Candidate fish habitat metrics derived from FHTI values were evaluated and compared with selected core metrics to assess the utility of the index for inclusion in the Maryland fish index of biotic integrity (IBI). Classification efficiency (CE) testing of approximately 12 candidate metrics revealed significant discrimination between IBI reference (minimally affected) and degraded stream site locations. Highest CEs among candidate fish habitat metrics were equivalent or higher than CEs obtained for metrics used in the current version of the Maryland fish IBI. Metric performance suggested that physical habitat tolerance indices have significant potential to improve accuracy and effectiveness of existing regional fish IBIs in the mid-Atlantic region.

Statewide or region-based indices measuring the biological condition or health of aquatic resources rely on the use of integrated physical, chemical, and biological monitoring data adapted for a variety of geographic areas and taxonomic groups (Karr 1987; Gibson et al. 1996). One of the most widely used and effective stream assessment approaches is the multimetric indicator of condition, known as the index of biotic integrity (IBI; Karr 1981; Karr et al. 1986). The IBI rates the existing structure, composition, and functional organization of fish assemblages through an array of attributes (metrics) to form a single ecologically based index of water resource quality (Fausch et al. 1990; Gibson et al. 1996). Selected fish community metrics, representing such aspects as species abundance, richness, trophic composition, and pollution tolerance, have been used in the development of a working fish IBI in several states including Ohio (Ohio EPA 1987) and Maryland (Boward et al. 1999). Although combinations of existing (core) metrics have been successful in many watershed-based management programs, the development of new metrics to reflect regional differences of both species assemblages and impact types may lead to further refinements of existing state and regional IBIs (Roth et al. 2000).

A critical component in the evaluation of stream impairment using multimetric approaches is the assessment of instream physical habitat quality. The combination of numerous instream characteristics (microhabitats), such as velocity, depth, substrate, and cover, provide insights as to the ability of a stream to support a healthy aquatic community and have been directly linked to biological integrity of the resource (NRC 1992; Roth et al. 1998, 1999). Barbour and Stribling (1991) summarized that in the absence of water quality problems, direct responses of the biota, such as a reduction in species richness or abundance or a change in functional organization, can be expected with declines in the quality of instream or riparian habitat. In this study, statewide biological monitoring information was used to examine species-level responses to ranges of habitat quality in streams that, when aggregated into a habitat-related sensitivity measure, may prove useful for refining fish IBIs in Maryland and the Mid-Atlantic region.

The objectives of this study were to (1) assess and document the relationships between aquatic habitat condition and composition and the struc-

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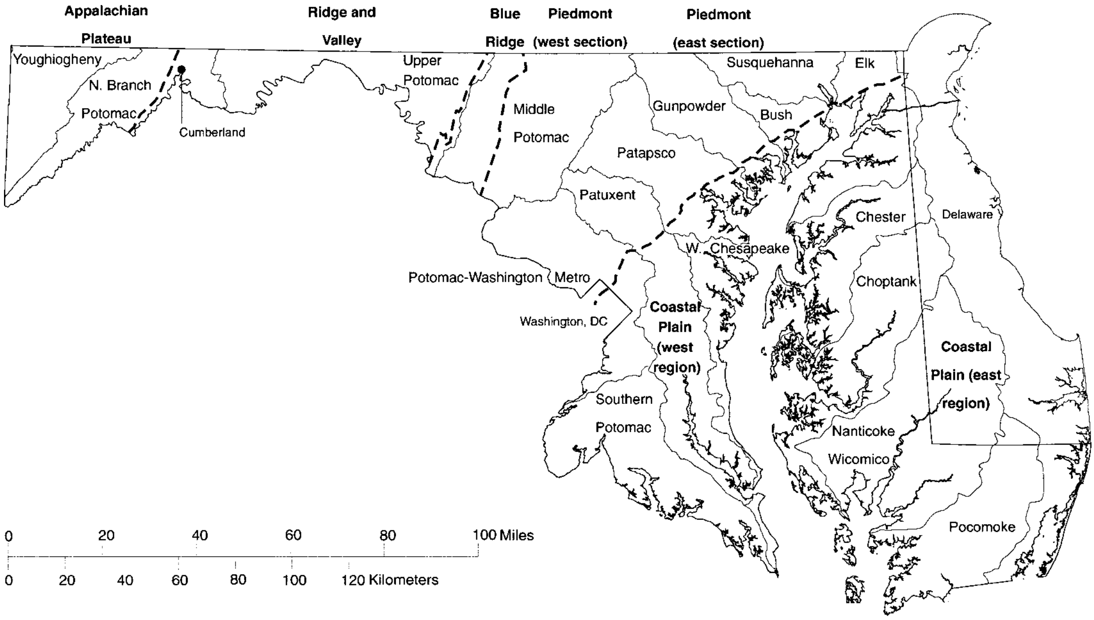

FIGURE 1.—Map of the assessment study area. The 1995–1997 Maryland Biological Stream Survey collected information on water chemistry, physical habitat, and stream biota throughout the 17 major drainage basins in the state (indicated by solid lines and regular type). Seven physiographic provinces (indicated by dashed lines and bold type) transect the drainage area boundaries (adapted from Reger 1995).

ture of monitored fish populations and (2) provide an effective measure of fish habitat tolerance that may lead to a more integrated and accurate assessment of biological condition within stream ecosystems. To develop habitat tolerance ratings for stream fishes, instream habitat quality characteristics were compared with fish presence–absence and abundance data from sampling locations across Maryland. Through candidate metric evaluation, I tested the ability of a fish habitat tolerance index (FHTI), at the species level, to accurately quantify biological condition within Maryland streams. The performance of several fish-habitat-related metrics were compared with the metrics currently used for Maryland's fish IBI. A working FHTI, if used concurrently with other core metrics describing biological condition, may improve accuracy of existing state and regional IBIs.

Study Area

The study area comprised 17 drainage basins across the state of Maryland. The population of first-order through third-order streams encompasses about 90% of all stream and river miles in Maryland. Because the character of an aquatic ecosystem depends to a large extent upon the landscape it drains, spatial patterns in aquatic ecosystems should correspond to patterns in the landscape (Larsen et al. 1986). General patterns of fish distribution ranges can be observed through simple analysis of the physiographic provinces and the drainage areas in the study area. Figure 1 depicts the orientation of drainage basins in Maryland relative to the seven physiographic provinces (J. Reger, 1995 memorandum to J. Perdue, A. Raspberry, and E. Bradley, on digital files and metadata for draft physiographic map of Maryland).

Methods

Information Source

The relationships between fish presence/abundance and physical habitat were developed based on information from the Maryland Biological Stream Survey (MBSS). The first round of the MBSS was a multiyear (1995–1997), probability-based sampling program consisting of nearly 1,000 stream sampling sites throughout Maryland (MDNR 1997). The intent of the survey was to characterize the current condition of Maryland streams; establish a baseline for trend detection; determine relationships between stressors and physical, chemical, and biological responses; identify areas for protection and restoration; and provide an inventory of biological resources.

A multiyear lattice sampling design (Heimbuch et al. 1999) was used in the survey and sampling was restricted to nontidal, third-order and smaller stream reaches, as determined from a 1:250,000-scale base map. The stream reaches were then divided into nonoverlapping 75-m stream segments; these were the fundamental sampling units from which biological, water chemistry, and physical habitat data were collected. Fish sampling and physical habitat evaluations were conducted during the low-flow period in summer. Fish were sampled using double-pass electrofishing (DC) with backpack units; block nets were placed at each end of the segment. Heimbuch et al. (1997) provides a detailed statistical description of the inherent accuracy and biases of MBSS sampling techniques. Water quality variables such as dissolved oxygen (DO), pH, temperature, and conductivity were also measured at each site during the summer index period. An additional suite of water chemistry characteristics, including acid neutralizing capacity, were measured during spring.

Assessment of Physical Habitat Condition

One objective of the 1995–1997 MBSS was to assess the physical habitat conditions at all stream segments as a means of determining the importance of physical habitat to the biological integrity and fishability of freshwater streams in Maryland. Thirteen characteristics of stream habitat were qualitatively assessed and compared with fish IBI scores to identify which variables showed the strongest association with biotic integrity across all basins in Maryland (Roth et al. 1997). The following five habitat characteristics had a strong association with the fish IBI and were used in this study: (1) instream habitat structure, (2) epifaunal substrate, (3) velocity-versus-depth diversity, (4) pool-glide-eddy quality, and (5) riffle quality.

The procedures used for habitat assessments were adapted from two currently used methodologies: the Environmental Protection Agency's Rapid Bioassessment Protocols (RPBs; Plafkin et al. 1989), as modified by Barbour et al. (1999), and the Ohio Environmental Protection Agency's Qualitative Habitat Evaluation Index (QHEI; Ohio EPA 1987; Rankin 1989). Ratings of 0–20 were assigned to each of the five characteristics analyzed based on physical habitat condition at each sampling site. Scores for each of these characteristics were then grouped into four distinct categories used in field observations—poor (0–5 points), marginal (6–10), suboptimal (11–15) and optimal (16–20)—that were used throughout this assessment (Table 1, as adapted from Kazyak 1995). Habitat characteristics were as follows:

Instream habitat stucture.—The amount of stable habitat structure in a stream. Scores represent the amount of rocks, logs, rootwads, undercut banks, and aquatic plants available for fish. Other materials providing habitat and cover for fish were counted as well.

Epifaunal substrate.—The amount and variety of hard, stable substrates available to benthic macroinvertebrates. Environments suitable for macroinvertebrates are typically stream bottoms free from fine sediments or flocculent materials (Roth et al. 1997).

Velocity versus depth diversity.—The variability in velocity-versus-depth streamflow regimes (slow-shallow, slow-deep, fast-shallow, and fast-deep) provides a measure of the heterogeneity of available riffle and pool microhabitats.

Pool-glide-eddy quality.—The variety, extent, and spatial complexity of slow or still-water habitats. For high-gradient segments, functionally important slow-water habitat may exist in the form of larger eddies.

Riffle quality.—The depth, variety, complexity, and functional importance of riffle and run habitat within the sampled segment.

Prerequisite Steps in Data Analysis

Stream site selection.—The 1995–1997 MBSS collected information on numerous anthropogenic stressors related to the potential decline in aquatic resources in Maryland streams. Factors including acidification and low dissolved oxygen are known to have detrimental effects on fish and other aquatic biota (Roth et al. 2000). Because this study was designed to assess the effects of physical habitat condition on fish communities, an attempt was made to remove sites that exhibited poor water quality characteristics. Based on studies involving fish community responses to acidification and low dissolved oxygen concentration (DO) levels (Baker et al. 1990; Smale and Rabeni 1995), I assigned the following threshold values: pH = 5, acid neutralizing capacity = 0 microequivalents/L, and ambient DO = 1 mg/L. Using these thresholds, a total of 889 stream sampling locations remained for analysis.

Species selection.—Maryland contains more than 88 species of freshwater fish (Lee et al. 1976). More than 72 species are native to the Chesapeake Bay drainage, and approximately 16 species are known to be introduced. A total of 85 native and nonnative species were collected during the 1995–1997 MBSS summer sampling period. Certain spe-

TABLE 1.—Assessment guidelines utilized in the collection of physical habitat conditions within Maryland streams (adapted from Kazyak 1995).

Habitat characteristic	Habitat assessment scoring descriptions (score range)			
	Poor (0–5)	Marginal (6–10)	Suboptimal (11–15)	Optimal (16–20)
Instream habitat structure	<10% stable habitat; lack of habitat is obvious	10–30% mix of stable habitat; habitat availability less than desirable	30–50% mix of stable habitat; adequate habitat	>50% mix of a variety of cobble, boulder, submerged logs, undercut banks, rootwads, etc.
Epifaual substrate	Stable substrate lacking, or particles are more than 75% surrounded by fine sediment or flocculent material	Large boulders or bedrock prevalent; cobble, woody debris uncommon	Abundance of cobble with gravel or boulders common, or woody debris, aquatic vegetation, undercut banks common but not prevalent	Preferred substrate abundant, stable and at full colonization potential (riffles well developed and predominated by cobble, or woody debris prevalent)
Velocity–depth diversity	Predominated by 1 velocity–depth category (usually pools)	Only 2 of 4 habitat categories present	Only 3 of 4 habitat categories present	Slow (<0.3 m/s), deep (>0.5 m); slow, shallow (<0.5 m); fast (>0.3 m/s), deep; fast, shallow habitats all present
Pool–glide–eddy (PEG) quality	PEG habitat minimal, with maximum depth <0.2 m	<10% PEG habitat, shallows (<0.2 m) prevalent, slow-water areas with little cover	10–50% PEG habitat, deep (>0.5 m) areas present, or >50% slow water with little cover	>50% PEG habitat, both deep (>0.5 m) and shallow (<0.2 m) present; complex cover or depth >1.5 m
Riffle or run (RR) quality	RR depth <1 cm, or RR substrates concreted	RR depth generally 1–5 cm; primarily a single current velocity	RR depth generally 5–10 cm, variety of current velocities	RR depth generally >10 cm, maximum depth >50 cm; substrate stable, variety of current velocities

cies were sampled so infrequently that analyzing their responses to changes in habitat condition across stream sites was not feasible, simply because of insufficient information on occurrence. For this paper, species occurring in less than 2% of the sites sampled were eliminated from consideration. A total of 54 species remained for analysis. Distributions of species in Maryland (Figure 2, showing northern hog sucker *Hypentelium nigricans*) were compared with historical observations (Lee et al. 1981) to test for completeness of the MBSS dataset.

Data Analysis

The methods used for this study strictly relate attributes of species occurrence and abundance and physical habitat condition for all 889 site locations; thus, there was no attempt to stratify the data based on physiographic or temperature preference of some species. This statewide assessment considers all 54 species across all basins in the study area.

The initial step in data analysis was to develop an approach that would best capture individual species responses to stream habitat degradation. Species presence–absence and abundance data have historically been used to assess environmental condition in stream ecosystems (Leonard and Orth 1986; Karr et al. 1986; Ohio EPA 1987). As a measure of comparison, both presence and abundance data were used to evaluate fish habitat relationships.

Fish presence by stream site.—Each stream site sampled in the MBSS dataset contains information on the occurrence and abundance of individual species. For each species, sites containing one or more individuals were grouped into one of four scoring categories for each of the habitat characteristics. Within each habitat scoring category, the percent occurrence of each species was calculated and used in developing the habitat tolerance index.

Fish abundance by stream site.—For this portion of the analysis, the total catch for each sampled stream segment (i.e., the sum of two electrofishing passes) was grouped into one of four scoring categories for each of the habitat characteristics. Abundance was then calculated as a mean value with corresponding SE for each of the scoring categories. Mean abundance values include all sites in each scoring category.

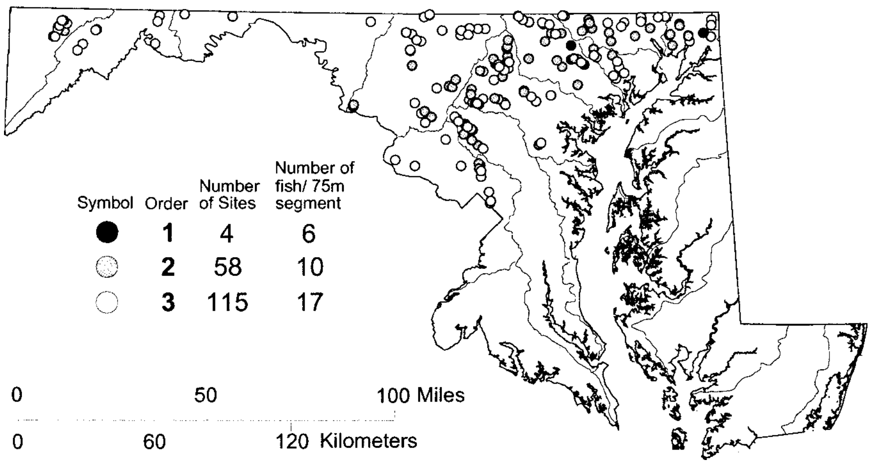

FIGURE 2.—Distribution of the northern hog sucker in the 17 major drainage basins in Maryland. Circles denote sites at which at least one individual was sampled during 1995–1997; the term ''order'' refers to the order of the streams sampled.

For each of the habitat characteristics, raw occurrence and abundance values at each site were plotted against habitat scores (Figure 3, showing northern hog sucker) to illustrate species responses across the habitat quality scoring range. The relative strength of relation between fish presence, abundance, and physical habitat condition (Table 2, showing northern hog sucker) provided the basis for development of the species-level habitat tolerance index for stream fish.

Fish Habitat Tolerance Index Development

Combining individual habitat parameters.—To develop a measure of overall habitat quality for each stream site, scores for each of the five habitat characteristics were combined and the mean value was determined. Using the combined habitat quality score, 51 sites fell into the poor (0–5 scores), 262 into the marginal (6–10), 436 into the suboptimal (11–15), and 140 into the optimal (16–20) categories.

Using the combined measure of habitat quality, habitat tolerance was determined by comparing species presence and abundance values in sites exhibiting lower scoring ranges relative to those in sites exhibiting higher ranges. Each of the four habitat scoring categories was utilized for comparisons between species presence and abundance versus habitat quality.

Development of a normalized difference index value.—A normalized difference approach was used to compare species presence and abundance across habitat scoring categories. Normalized difference has been successfully used in various remote sensing studies to assess vegetative canopy distribution declines or shifts (Lillesand and Kiefer 1994). The principles of normalized difference have been applied in the normalized difference vegetation index, a commonly used vegetation index that transforms multiple image bands into a single image representing the distribution of green vegetation.

The equation to obtain a normalized difference index value (NDIV) comparing two habitat categories is $(P_{16-20} - P_{6-10})/(P_{16-20} + P_{6-10})$, where P_{16-20} is the percent occurrence of species for the optimal scoring category (16–20) and P_{6-10} is the percent occurrence for the marginal scoring category (6–10). The index values represent the normalized difference in fish presence between scoring categories. The greater the difference in species presence and abundance values across high to low habitat scoring ranges, the greater the index value. A higher index value potentially indicates a stronger correlation between species presence or abundance and habitat quality. This index utilizes information from the entire range of scores (i.e., 0–20) in the determination of tolerance.

A single NDIV was calculated for each of the 54 species analyzed by means of the following formulas for species presence and absence, respectively: PNDIV $= (P_4 - P_2)/(P_4 + P_2) + (P_3 - P_1)/(P_3 + P_1)$ and ANDIV $= (A_4 - A_2)/(A_4 + A_2) + (A_3 - A_1)/(A_3 + A_1)$, where P = the percent occurrence of species within each habitat scoring category and A = mean abundance of species within each habitat scoring category. Habitat scoring

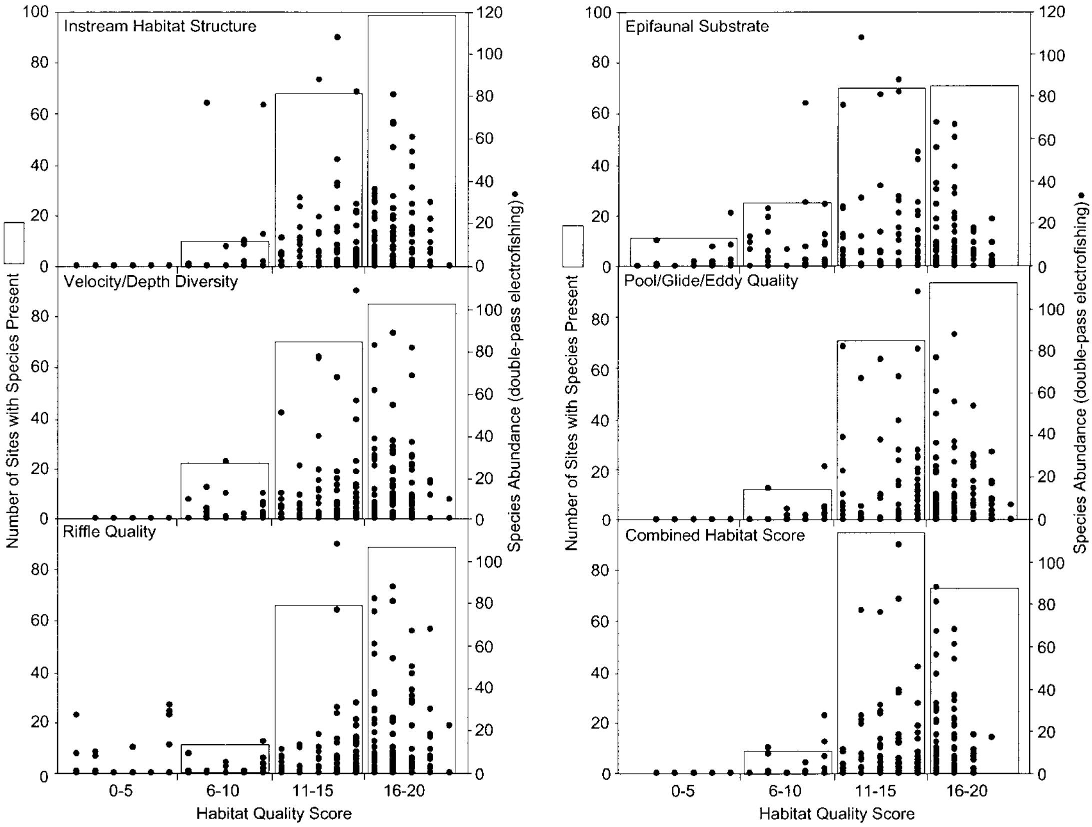

FIGURE 3.—Plots showing the total number of sampled sites at which northern hog suckers were present and the total number of individuals at each site for the categorical range of scores describing five qualitatively assessed physical habitat variables. The combined habitat score is the mean of the five variable scores.

categories were defined as follows: 1 (0–5), 2 (6–10), 3 (11–15), and 4 (16–20).

Habitat tolerance for all species was estimated by summing the NDIV across the scoring categories that were compared. Index values of PNDIV and ANDIV were summed to obtain an overall total (NDIVTOT) for each species. Index values less than zero indicate a negative correlation between species presence or abundance values and habitat scores, whereas index values near zero in-

TABLE 2.—Relationships between northern hog sucker presence, abundance, and physical habitat condition for 889 sampling sites in Maryland. Values for presence and abundance are grouped by physical habitat scoring category, reflecting various states of stream habitat: poor (0–5), marginal (6–10), suboptimal (11–15), and optimal (16–20). Values for presence include the number of sites within that scoring category where at least one individual was sampled, and abundance includes the mean species abundance in that scoring category for sites listed in presence. The combined habitat score is included as the mean of five habitat characteristic scores.

Habitat characteristic	Scoring category: Presence				Abundance			
	0–5	6–10	11–15	16–20	0–5	6–10	11–15	16–20
Instream habitat	0	10	68	99	0	22	14	14
Epifaual substrate	11	25	70	71	6	13	17	13
Velocity–depth diversity	0	22	70	85	0	6	14	17
Pool–glide–eddy quality	0	12	71	94	0	6	17	14
Riffle quality	11	11	66	89	15	5	11	18
Combined habitat score (mean)	0	9	95	73	0	9	12	18

TABLE 3.—Species presence and abundance values by habitat scoring category for the combined habitat quality score for 54 fish sampled in 1995–1997. Values represent the percent occurrence (PO) and the average number of fish captured (*A*) within each scoring category. Scoring categories: 1 = 0–5, 2 = 6–10, 3 = 11–15, and 4 = 16–20. Values of PO and *A* were used for habitat tolerance index development.

		Presence (% occurrence)				Abundance (mean [SE])			
Family	Species	PO_1	PO_2	PO_3	PO_4	A_1	A_2	A_3	A_4
Petromyzontidae	Least brook lamprey	0.08	0.17	0.15	0.08	0.75	4.59	2.00	0.71
	Lampetra aepyptera					(0.50)	(1.73)	(0.45)	(0.44)
	Sea lamprey	0.00	0.03	0.05	0.07	0.00	0.20	0.25	0.57
	Petromyzon marinus					(0.00)	(0.08)	(0.08)	(0.29)
Anguillidae	American eel	0.20	0.39	0.39	0.41	1.82	7.65	8.23	19.5
	Anguilla rostrata					(1.19)	(1.14)	(0.78)	(3.53)
Esocidae	Chain pickerel	0.02	0.10	0.11	0.08	0.02	0.56	0.44	0.18
	Esox niger					(0.02)	(0.19)	(0.08)	(0.06)
	Redfin pickerel	0.16	0.25	0.13	0.04	1.65	2.55	1.7	0.26
	Esox americanus americanus					(0.62)	(0.63)	(0.36)	(0.15)
Umbridae	Eastern mudminnow	0.41	0.40	0.21	0.11	36.75	24.36	9.89	1.71
	Umbra pygmaea					(14.23)	(3.72)	(2.00)	(0.66)
Cyprinidae	Blacknose dace	0.22	0.56	0.80	0.86	5.55	55.73	91.29	73.14
	Rhinichthys atratulus					(2.37)	(6.62)	(6.55)	(7.88)
	Bluntnose minnow	0.00	0.10	0.22	0.29	0.00	16.26	16.61	10.14
	Pimephales notatus					(0.00)	(6.63)	(2.85)	(2.41)
	Central stoneroller	0.00	0.06	0.25	0.46	0.00	2.19	14.24	37.75
	Campostoma anomalum					(0.00)	(1.05)	(3.32)	(9.65)
	Common shiner	0.00	0.04	0.28	0.50	0.00	0.24	6.47	32.94
	Luxilus cornutus					(0.00)	(0.12)	(1.18)	(6.02)
	Creek chub	0.14	0.24	0.17	0.11	3.06	7.31	4.40	1.32
	Semotilus atromaculatus					(2.27)	(2.08)	(1.17)	(0.64)
	Cutlips minnow	0.00	0.03	0.28	0.51	0.00	0.60	5.63	18.69
	Exoglossum maxillingua					(0.00)	(0.38)	(0.87)	(2.38)
	Fallfish	0.00	0.14	0.26	0.24	0.00	2.92	6.96	4.94
	Semotilus corporalis					(0.00)	(0.66)	(1.20)	(1.02)
	Fathead minnow	0.00	0.03	0.03	0.01	0.00	1.31	0.05	0.06
	Pimephales promelas					(0.00)	(0.80)	(0.01)	(0.06)
	Golden shiner	0.16	0.20	0.12	0.08	5.39	3.62	0.97	0.51
	Notemigonus crysoleucas					(3.43)	(0.96)	(0.29)	(0.28)
	Longnose dace	0.00	0.10	0.53	0.79	0.00	1.45	20.6	44.21
	Rhinichthys cataractae					(0.00)	(0.44)	(2.02)	(4.84)
	River chub	0.00	0.02	0.13	0.35	0.00	0.15	2.53	11.89
	Nocomis micropogon					(0.00)	(0.11)	(0.54)	(2.8)
	Rosyface shiner	0.00	0.00	0.01	0.12	0.00	0.00	0.09	1.11
	Notropis rubellus					(0.00)	(0.00)	(0.05)	(0.52)
	Rosyside dace	0.04	0.20	0.44	0.59	0.25	5.85	24.11	36.81
	Clinostomus funduloides					(0.2)	(1.59)	(2.56)	(5.17)
	Satinfin shiner	0.00	0.09	0.13	0.23	0.00	1.12	2.19	3.91
	Notropis hypselopterus					(0.00)	(0.35)	(0.50)	(1.50)
	Silverjaw minnow	0.00	0.00	0.06	0.08	0.00	0.01	1.43	0.52
	Notropis buccatus					(0.00)	(0.01)	(0.70)	(0.21)
	Spotfin shiner	0.00	0.02	0.06	0.06	0.00	0.06	0.56	0.58
	Cyprinella spiloptera					(0.00)	(0.04)	(0.18)	(0.27)
	Spottail shiner	0.00	0.02	0.08	0.19	0.00	1.08	4.91	4.54
	Notropus hudsonius					(0.00)	(1.04)	(1.34)	(1.64)
	Swallowtail shiner	0.04	0.12	0.20	0.19	0.08	5.04	6.08	6.64
	Notropis procne					(0.06)	(2.29)	(1.16)	(2.00)
	Creek chubsucker	0.10	0.40	0.66	0.74	3.24	19.45	26.27	21.21
	Erimyzon oblongus					(1.80)	(3.03)	(1.94)	(2.71)
Catostomidae	Northern hog sucker	0.00	0.03	0.22	0.52	0.00	0.31	2.64	9.39
	Hypentelium nigricans					(0.00)	(0.14)	(0.48)	(1.43)
	White sucker	0.02	0.34	0.67	0.83	0.04	10.08	24.15	32.61
	Catostomus commersoni					(0.04)	(2.36)	(2.12)	(4.19)
Ictaluridae	Brown bullhead	0.08	0.12	0.12	0.06	3.63	7.38	0.86	0.19
	Ameiurus nebulosus					(2.74)	(5.85)	(0.29)	(0.09)
	Margined madtom	0.00	0.09	0.24	0.39	0.00	0.5	2.62	9.32
	Noturus insignis					(0.00)	(0.14)	(0.45)	(1.90)
	Tadpole madtom	0.06	0.16	0.09	0.04	0.31	2.15	2.11	0.43
	Noturus gyrinus					(0.26)	(0.60)	(0.59)	(0.26)

TABLE 3.—Continued.

Family	Species	Presence (% occurrence)				Abundance (mean [SE])			
		PO_1	PO_2	PO_3	PO_4	A_1	A_2	A_3	A_4
	Yellow bullhead	0.04	0.09	0.16	0.16	0.29	0.50	0.75	0.91
	Ameiurus natalis					(0.27)	(0.15)	(0.16)	(0.31)
Salmonidae	Brook trout	0.02	0.03	0.10	0.11	0.69	0.55	2.11	3.39
	Salvelinus fontinalis					(0.69)	(0.29)	(0.45)	(1.17)
	Brown trout	0.00	0.02	0.12	0.27	0.00	0.15	2.71	2.95
	Salmo trutta					(0.00)	(0.08)	(0.88)	(0.80)
	Rainbow trout	0.00	0.01	0.05	0.11	0.00	0.03	0.12	0.39
	Oncorhynchus mykiss					(0.00)	(0.02)	(0.06)	(0.13)
Aphredoderidae	Pirate perch	0.20	0.18	0.12	0.07	1.04	3.23	2.13	1.04
	Aphredoderus sayanus					(0.35)	(0.67)	(0.54)	(0.42)
	Banded killifish	0.02	0.03	0.02	0.02	0.08	0.63	0.15	0.11
	Fundulus diaphanus					(0.08)	(0.47)	(0.07)	(0.07)
	Mummichog	0.02	0.03	0.02	0.01	0.35	1.68	2.04	0.93
	Fundulus heteroclitus					(0.35)	(1.10)	(1.06)	(0.90)
Cottidae	Mottled sculpin	0.00	0.12	0.34	0.59	0.00	14.11	52.05	157.03
	Cottus bairdi					(0.00)	(4.42)	(6.93)	(20.86)
	Potomac sculpin	0.04	0.08	0.17	0.21	1.82	5.43	14.59	15.69
	Cottus girardi					(1.80)	(1.75)	(2.28)	(3.63)
Centrarchidae	Banded sunfish	0.04	0.04	0.02	0.01	0.08	0.61	0.10	0.01
	Enneacanthus obesus					(0.05)	(0.37)	(0.05)	(0.01)
	Bluegill	0.16	0.34	0.44	0.46	4.80	6.04	5.54	5.14
	Lepomis macrochirus					(2.80)	(1.18)	(0.68)	(1.17)
	Bluespotted sunfish	0.06	0.13	0.07	0.05	0.49	2.91	1.72	0.33
	Enneacanthus gloriosus					(0.43)	(0.84)	(0.48)	(0.19)
	Green sunfish	0.00	0.12	0.23	0.25	0.00	1.79	3.76	2.46
	Lepomis cyanellus					(0.00)	(0.55)	(0.93)	(0.92)
	Largemouth bass	0.10	0.20	0.24	0.32	0.92	1.06	1.48	5.26
	Micropterus salmoides					(0.71)	(0.34)	(0.25)	(2.78)
	Pumpkinseed	0.18	0.34	0.31	0.29	6.00	3.28	3.09	1.99
	Lepomis gibbosus					(5.58)	(0.5)	(0.43)	(0.77)
	Redbreast sunfish	0.02	0.21	0.33	0.36	0.31	4.26	5.36	4.86
	Lepomis auritus					(0.31)	(1.14)	(0.65)	(1.15)
	Rock bass	0.00	0.04	0.12	0.19	0.00	0.40	0.87	0.94
	Ambloplites rupestris					(0.00)	(0.16)	(0.17)	(0.25)
	Smallmouth bass	0.00	0.02	0.14	0.26	0.00	0.05	0.56	1.35
	Micropterus dolomieu					(0.00)	(0.03)	(0.10)	(0.34)
Percidae	Fantail darter	0.00	0.11	0.22	0.21	0.00	2.97	9.78	7.82
	Etheostoma flabellare					(0.00)	(0.77)	(1.49)	(2.16)
	Greenside darter	0.00	0.02	0.10	0.17	0.00	0.09	1.9	2.51
	Etheostoma blennioides					(0.00)	(0.05)	(0.5)	(0.73)
	Shield darter	0.00	0.01	0.05	0.05	0.00	0.15	0.62	0.24
	Percina peltata					(0.00)	(0.11)	(0.20)	(0.15)
	Swamp darter	0.02	0.03	0.02	0.01	0.02	0.11	0.08	0.01
	Etheostoma fusiforme					(0.02)	(0.06)	(0.04)	(0.01)
	Tessellated darter	0.16	0.35	0.50	0.62	1.37	12.26	16.66	16.49
	Etheostoma olmstedi					(0.60)	(2.29)	(1.61)	(2.4)
	Yellow perch	0.00	0.07	0.06	0.06	0.00	0.53	0.35	0.29
	Perca flavescens					(0.00)	(0.32)	(0.11)	(0.11)

dicate minimal to no correlation between species values and habitat quality. Three designations of habitat tolerance were developed for the 54 species analyzed: (1) tolerant, (2) moderately intolerant, and (3) intolerant.

Comparison of species across regional strata.—To document species-level responses associated with habitat condition in Maryland streams, a consistent framework was needed to interpret species tolerance measurements across the large geographic area covered by the 1995–1997 MBSS. Ecologically relevant stratification can provide a conceptual and operational framework for defining biotic potential or biotic limitations (Hughes 1990). The framework used for this assessment involved grouping species into three geographic strata (Coastal Plain, Eastern Piedmont, and Highlands), identified in prior studies as supporting distinctly different, naturally occurring species assemblages (Roth et al. 2000).

Species groups were determined from historical records defining approximate distributions of native fish populations in Maryland (Lee et al. 1981) and visual inspection of species distribution maps from the 1995–1997 MBSS (Pirhalla, unpublished). Species exhibiting multiple geographic associations were grouped in the regions in which they were most typically distributed. Species tolerance index values (NDIVTOT) were plotted across regional strata to reveal patterns of habitat tolerance among species groups.

Fish Habitat Metric Testing

Using an IBI calibration data set of reference (minimally affected) and degraded sites established from a suite of physiochemical criteria sampled from the MBSS (Roth et al. 2000), candidate fish habitat metrics were evaluated to determine the responsiveness of each metric for discriminating between minimally impacted and degraded sites. Most metrics tested were calculated by averaging tolerance index values based on the number, identity, and trophic composition of species captured at sites in the calibration dataset (e.g., the total number of moderately intolerant and intolerant insectivores and top predators caught). Candidate metrics were analyzed across all three regional strata. Classification efficiency (CE), calculated as the percentage of reference and degraded sites correctly classified by each metric, was performed on 12 individual habitat metrics and compared with the efficiencies of selected core metrics from a previous study (Roth et al. 2000).

Results

Fish Habitat Tolerance Rankings

Fish presence and abundance values used for FHTI development were compared across habitat quality scoring ranges (Table 3). A total of 27 species had no occurrence in the poor (0–5) scoring category, whereas two species, rosyface shiner and silverjaw minnow, had no occurrence in the marginal (6–10) category. Species such as redfin pickerel, eastern mudminnow, creek chub, golden shiner, and pirate perch had lowest recorded occurrence and abundance in the optimal (16–20) category. Eastern mudminnows had both highest recorded occurrence and abundance in the poor (0–5) category.

The normalized difference approach yielded 54 unique habitat tolerance rankings for individual species. Overall index values ranged from -2.34 to $+3.93$. For this analysis, threshold values for overall habitat tolerance were established as approximately the 90th and 45th percentiles (Table 4). Species most sensitive to habitat disturbance represent index values above the 90th percentile. Species between the 45th and 90th percentiles were considered moderately intolerant to habitat degradation. Species below the 45th percentile were considered tolerant. Table 5 summarizes species index values used in the development of habitat tolerance. Species were rank ordered by overall NDIVTOT from least to greatest (Figure 4). Spearman's rank correlations were calculated for the index values of PNDIV and ANDIV ($r = 0.9409$, $P < 0.0001$).

TABLE 4.—Evaluation of overall habitat tolerance for 54 fish species analyzed. Breaks in designation between intolerant and moderately intolerant species are based on the 90th and 45th percentiles, respectively, for the range of index values recorded.

Tolerance index range	Habitat tolerance	Number of species
−4.00 to 1.99	Tolerant	24
2.00 to 3.79	Moderately intolerant	24
3.80 to 4.00	Intolerant	6

Regionalization of Tolerance Rankings

Three geographic strata (Coastal Plain, Eastern Piedmont, and Highlands) were used to interpret regional differences in species habitat tolerance levels. A fourth species group, Cosmopolitan, was added to the Eastern Piedmont group. Fish habitat tolerance among species groups varied considerably across regions (Figure 5), Coastal Plain species (16) being most tolerant to habitat degradation, followed by Cosmopolitan (8), Eastern Piedmont (15), and Highlands species (20).

Coastal Plain.—The Coastal Plain group (Figure 5a) consisted of 15 tolerant and 1 moderately intolerant species (the sea lamprey). Geographic distributions of species were predominantly restricted to the eastern and western regions of the Coastal Plain. Trophic classifications developed by Jenkins and Burkhead (1993) identify the species in this group as invertivores (9), filter feeders (2), top predators (2), generalists (2), and omnivores (1).

Cosmopolitan and Eastern Piedmont.—The Cosmopolitan and Eastern Piedmont group (Figure 5b) consisted of intolerant (3), moderately intolerant (11), and tolerant (9) species. Moderately intolerant and intolerant species are mainly distributed throughout the Eastern Piedmont, although some populations ranged into western sections of the

TABLE 5.—Normalized difference index values (NDIVs) calculated for the combined habitat quality score for 54 fish species sampled in 1995–1997. The symbol P stands for percent occurrence, the symbol A for mean abundance. Total values ($NDIV_{TOT}$) represent the sums of the NDIV values that were compared. See text for additional details.

	Presence		Abundance		
	$NDIV_1$	$NDIV_2$	$NDIV_3$	$NDIV_4$	$NDIV_{TOT}$
Species	$\left(\frac{P_4 - P_2}{P_4 + P_2}\right)$	$\left(\frac{P_3 - P_1}{P_3 + P_1}\right)$	$\left(\frac{A_4 - A_2}{A_4 + A_2}\right)$	$\left(\frac{A_3 - A_1}{A_3 + A_1}\right)$	$\left(\sum_{i=1}^{4} NDIV_i\right)$
Eastern mudminnow	−0.56	−0.33	−0.87	−0.58	−2.34
Golden shiner	−0.43	−0.13	−0.75	−0.70	−2.01
Banded sunfish	−0.71	−0.42	−0.98	0.14	−1.97
Brown bullhead	−0.36	0.22	−0.95	−0.62	−1.71
Redfin pickerel	−0.71	−0.10	−0.81	0.02	−1.61
Swamp darter	−0.66	0.03	−0.87	0.59	−0.92
Pirate perch	−0.44	−0.25	−0.51	0.34	−0.86
Creek chubsucker	−0.39	0.11	−0.69	0.18	−0.79
Bluespotted sunfish	−0.46	0.11	−0.80	0.56	−0.59
Banded killifish	−0.18	0.03	−0.69	0.32	−0.52
Pumpkinseed	−0.08	0.27	−0.24	−0.32	−0.37
Least brook lamprey	−0.36	0.31	−0.73	0.46	−0.32
Tadpole madtom	−0.63	0.23	−0.67	0.74	−0.32
Mummichog	−0.30	0.03	−0.29	0.71	0.14
Fathead minnow	−0.66	1.00	−0.91	1.00	0.44
Bluegill	0.16	0.48	−0.08	0.07	0.63
Chain pickerel	−0.12	0.69	−0.51	0.91	0.98
American eel	0.02	0.34	0.44	0.64	1.43
Largemouth bass	0.24	0.42	0.66	0.23	1.55
Yellow bullhead	0.28	0.60	0.29	0.44	1.62
Yellow perch	−0.06	1.00	−0.29	1.00	1.65
Tessellated darter	0.28	0.52	0.15	0.85	1.80
Blacknose dace	0.22	0.57	0.14	0.89	1.81
Creek chub	0.30	0.74	0.04	0.78	1.87
Swallowtail shiner	0.22	0.67	0.14	0.97	2.00
Redbreast sunfish	0.27	0.89	0.07	0.89	2.11
Bluntnose minnow	0.47	1.00	−0.23	1.00	2.24
Potomac sculpin	0.46	0.62	0.49	0.78	2.35
Brook trout	0.58	0.68	0.72	0.51	2.49
Fallfish	0.25	1.00	0.26	1.00	2.51
Green sunfish	0.36	1.00	0.16	1.00	2.52
Fantail darter	0.32	1.00	0.45	1.00	2.77
Sea lamprey	0.35	1.00	0.48	1.00	2.83
White sucker	0.42	0.94	0.53	1.00	2.89
Shield darter	0.74	1.00	0.24	1.00	2.97
Satinfin shiner	0.43	1.00	0.55	1.00	2.98
Rosyside dace	0.50	0.84	0.73	0.98	3.04
Rock bass	0.66	1.00	0.40	1.00	3.06
Spotfin shiner	0.58	1.00	0.80	1.00	3.38
Spottail shiner	0.85	1.00	0.62	1.00	3.46
Mottled sculpin	0.65	1.00	0.84	1.00	3.49
Margined madtom	0.62	1.00	0.90	1.00	3.52
Central stoneroller	0.77	1.00	0.89	1.00	3.66
Rainbow trout	0.82	1.00	0.87	1.00	3.69
Greenside darter	0.76	1.00	0.93	1.00	3.70
Longnose dace	0.78	1.00	0.94	1.00	3.72
Brown trout	0.84	1.00	0.90	1.00	3.75
Smallmouth bass	0.84	1.00	0.93	1.00	3.77
Northern hog sucker	0.88	1.00	0.94	1.00	3.81
Cutlips minnow	0.89	1.00	0.94	1.00	3.83
Common shiner	0.85	1.00	0.99	1.00	3.83
Silverjaw minnnow	0.91	1.00	0.97	1.00	3.88
River chub	0.92	1.00	0.97	1.00	3.89
Rosyface shiner	0.94	1.00	0.99	1.00	3.93

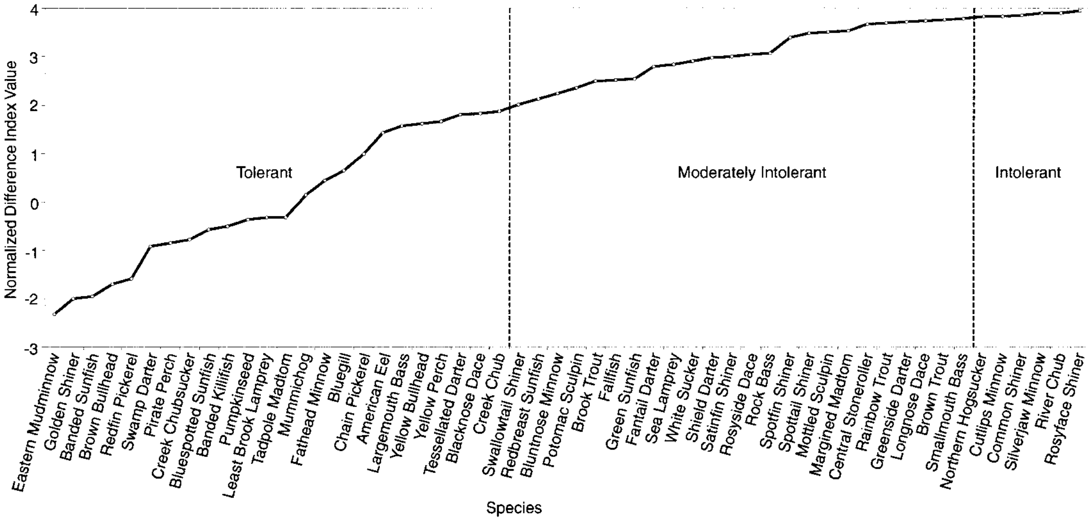

FIGURE 4.—Line plot showing habitat tolerance index values (normalized difference index values; see text) for 54 fish species sampled during 1995–1997. The dashed vertical lines indicate changes in tolerance categories.

Coastal Plain. Cosmopolitan species such as brown bullhead, yellow bullhead, fathead minnow, pumpkinseed, bluegill, largemouth bass, green sunfish, and redbreast sunfish, which were found throughout the state in nearly all major basins, were characterized primarily as tolerant to habitat disturbance. Species of this group consisted of invertivores (9), omnivores (8), generalists (4), top predators (1), and insectivores (1).

Highlands.—The Highlands group (Figure 5c) consisted of intolerant (6) and moderately intolerant (14) species. Species are distributed throughout the Piedmont, the middle and upper Potomac River, and the Youghiogheny drainages, but have minimal or no occurrence in the Coastal Plain. Trophic status and numbers of individuals consisted of invertivores (4), omnivores (4), top predators (3), insectivores (4), generalists (4), and algivores (1). Invertivores and omnivores make up the top six species showing general intolerance to declines in habitat conditions.

Fish Habitat Metric Evaluation

Fish-habitat-related metrics were evaluated and compared with core metrics to determine the utility of the FHTI for discriminating between impaired and nonimpaired sites. Metric performance was evaluated through classification efficiency (CE) testing of 12 candidate fish habitat metrics (Table 6).

Some IBI metrics, including several currently used for the Maryland fish IBI, include a correction for lower efficiency scoring in smaller headwater streams. For this analysis, no attempt was made to adjust values based on stream order or watershed size.

All combinations of metrics utilizing average tolerance value relative to abundance yielded consistently high CEs in the Eastern Piedmont and Highlands strata. Habitat tolerance metrics involving benthic species performed well overall with highest CEs in the Eastern Piedmont (95%). Metrics based on species richness (nonadjusted for watershed size) and combination metrics utilizing trophic structure and habitat tolerance yielded high CEs as well. In addition, metrics derived from individual habitat characteristics (instream habitat structure and riffle quality) scored well above the average of the IBI core metrics in the Highlands strata (90% versus 80%).

In most cases, utilizing average tolerance value relative to abundance boosted metric performance in all three regional strata. For the Coastal Plain, metric performance increased from 62% to 71% using NDIV > 0 but decreased to 67% with NDIV > 2. In general, metric CEs in the Coastal Plain were suppressed due to NDIV < 0 for species such as tadpole madtom and least brook lamprey, both of which exhibited increases in occurrence and abundance in degraded sites.

Discussion

Abundance Versus Presence–Absence

A significant positive relationship existed between aquatic habitat quality, as defined by nu-

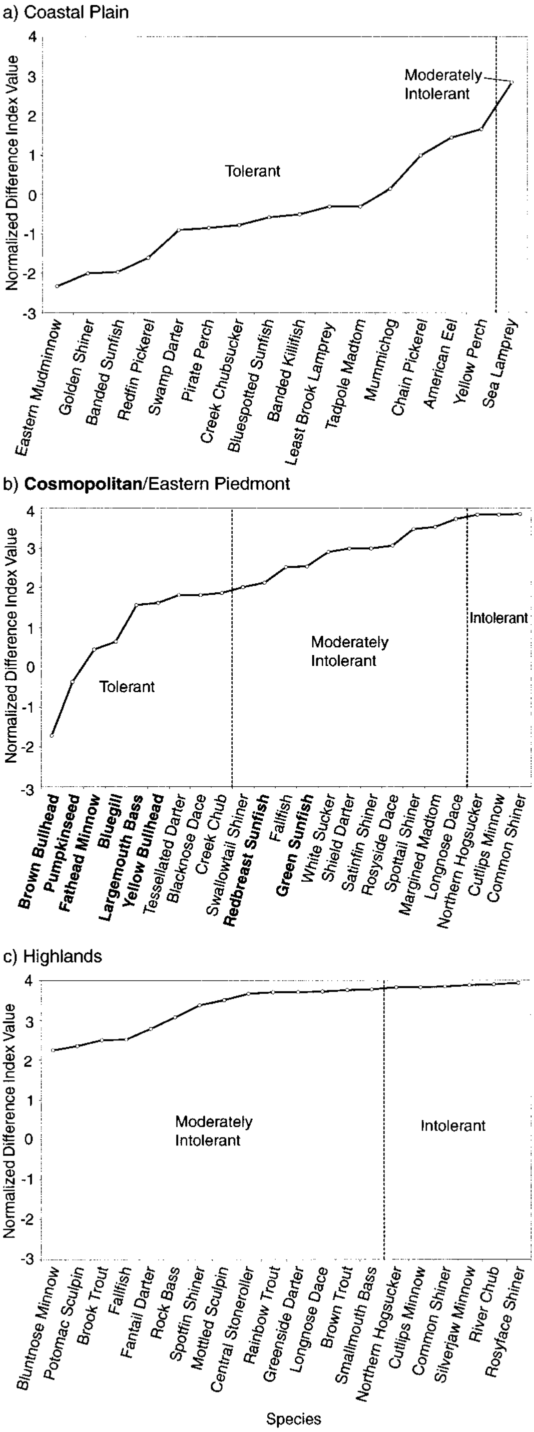

FIGURE 5.—Line plots showing habitat tolerance index values (normalized difference index values) across regional strata representing three species groups: **(a)** Coastal Plain, **(b)** cosmopolitan/Eastern Piedmont, and **(c)** Highlands. Index values are in ascending order; the dashed vertical lines indicate changes in tolerance categories.

merous instream characteristics, and biological condition in stream ecosystems (Rankin 1995; Barbour and Stribling 1991; Barbour et al. 1999; USEPA 1990), and as expected, fish presence–absence and abundance data provided useful information on individual species responses to the habitat characteristics examined. For most fish species, mean abundance data within a habitat category provided more insight into fish habitat responses than did percent occurrence within habitat categories. For example, the change in abundance between categories was much more pronounced than the change in percent occurrence for blacknose dace, creek chub, bluntnose minnow, fathead minnow, and creek chubsucker. In these cases, lower habitat scores resulted in increased abundance, whereas the change in percent occurrence was either minor or absent (Table 3). Given that species such as creek chub, fathead minnow, and creek chubsucker are considered pioneer species (Ohio EPA 1987), the marked increases in abundance with degradation are very consistent with the state of knowledge about these species (Leonard and Orth 1986; Karr et al. 1986). For other species generally thought to be sensitive to human disturbance, including brook trout (Steedman 1988) and longnose dace (Ohio EPA 1987), the change in abundance between categories was more pronounced than the change in percent occurrence.

Specific Relationships

A number of strong relationships between fish and habitat quality were documented in this study, but consistent patterns among trophic groups were not evident. Declines in habitat condition could result in shifts in benthic macroinvertebrate richness and composition and a subsequent reduction in specialist feeders (Berkman and Rabeni 1987; Leonard and Orth 1986). In Maryland streams, however, this trend was not clearly apparent; three of the top four most intolerant species (river chub, silverjaw minnow, and common shiner) are considered omnivores (Jenkins and Burkhead 1993). Perhaps the reasons for habitat sensitivity of these species are more related to spawning or early life history needs than dietary requirements.

Habitat Tolerance Rankings

Although thresholds for classifying species into tolerance categories were based on recommendations from previous work (Karr 1981; Karr et al. 1986), individual fish habitat tolerance rankings were consistent with known literature describing

TABLE 6.—Evaluation of 12 candidate fish-habitat-related metrics using classification efficiency testing. Geographic strata: CP = Coastal Plain, C/EP = Cosmopolitan/Eastern Piedmont, HI = Highlands.

Metric	CP (%)	C/EP (%)	H (%)
Combined Habitat Quality Score			
Fish abundance and composition			
1. Average tolerance value of all individuals caught	62	89	86
2. Average tolerance value of all individuals caught having a normalized difference index value of >0	71	89	86
3. Average tolerance value of intolerant and moderately intolerant species caught	67	89	86
4. Average tolerance value of benthic species caught	63	95	85
5. Average tolerance value of intolerants and moderately intolerant benthic species caught	71	89	86
6. Average tolerance value of intolerants and moderately intolerant insectivores, generalists, and top predators caught	69	92	81
7. Average tolerance value of insectivores, generalists, and top predators caught	69	92	81
Species richness and composition			
8. Number of intolerants and moderately intolerant benthic species (nonadjusted)	71	92	85
9. Number of intolerants and moderately intolerant insectivores, generalists, and top predators (nonadjusted)	69	89	88
Instream Habitat Structure			
10. Numbers of intolerant and moderately intolerant species caught (nonadjusted)	71	90	86
Fish abundance			
11. Average tolerance value of all individuals caught	56	89	90
Riffle Quality			
12. Average tolerance value of all individuals caught; average classification efficiencies for	65	89	90
the core combination of metrics (best performing)[a]	63	88	80

[a] Percentiles taken from Roth et al. (2000).

fish sensitivities to nonspecific stressor types (Ohio EPA 1987; Halliwell et al. 1999). Cyprinids contributed the top five most intolerant species in this study.

The habitat tolerance rankings presented here are also supported by population estimates derived by the MBSS (Roth et al. 1999); both the occurrence and abundance of moderately intolerant and intolerant species increased, sometimes dramatically, in reference versus degraded sites. The six native species listed as intolerant contribute less than 5% of all Maryland stream fishes, whereas just three species classified as tolerant (blacknose dace, creek chub, and eastern mudminnow) contribute more than one-third of Maryland fishes (Roth et al. 1999). Not surprisingly, blacknose dace (NDIV = 1.81) and creek chub (NDIV = 1.87) were the most tolerant of all species found in the Eastern Piedmont. Conversely, green sunfish (NDIV = 2.52) was least tolerant among all genus *Lepomis*.

Application of the FHTI

The concept of integrating tolerance information with distributional biosurvey data for application in state bioassessment programs has been successful in a variety of situations (Karr et al. 1986; Hilsenhoff 1988; Ohio EPA 1987; Plafkin et al. 1989; Roth et al. 2000). Hilsenhoff (1988) summarized the organic pollution tolerances of macroinvertebrate taxa through rapid field assessments of numerous stream samples throughout Wisconsin. In my study, testing of classification efficiency (CE) revealed that fish habitat metrics derived from FHTI values can effectively discriminate between reference and degraded streams. The highest CEs among candidate metrics were equivalent or higher than CEs obtained during development of the Maryland fish IBI (Roth et al. 2000). Because many of Maryland's stream fishes are common elsewhere in the Mid-Atlantic area, these results may be applicable in neighboring states as well.

Limitations of the Assessment

To meet the assessment objectives, 889 stream sampling locations were analyzed across Maryland. Even though the use of all 889 site locations in the development of a tolerance index for fish appears to be a reasonable approach, some limitations existed in the usage and application of these results.

Many sampling locations contained within the MBSS, and subsequently used in the study, had no occurrences of individual species. One reason for this involves the restricted geographic distributions of some of the species analyzed. Thus, the total number of sites with no occurrences of individuals was disproportionately high for many species. I did not stratify the dataset to compensate for these restricted distributions. Therefore, it was difficult to distinguish naturally limiting sites from degraded sites as they relate to species presence and abundance.

Also, the diverse physiography of Maryland affects not only the ecoregional characteristics of the landscape but overall stream morphology as well. As a result, physical habitat assessment scores can vary depending on geographic location. No attempt was made in this analysis to stratify geographic areas (e.g., Coastal Plain versus non-Coastal Plain) in determining the tolerance of species to habitat conditions. Thus, low habitat characteristic scores may not always be indicative of degradation within a sampled stream segment.

Problematic Issues in the Coastal Plain

The results of this study indicate that most fish species associated with Coastal Plain habitats are not sensitive to habitat quality. This issue is reflected in the fact that the ability of habitat tolerance metrics to discriminate between minimally impacted and degraded sites was reduced in the Coastal Plain compared with other areas of Maryland. Although it is possible that the measures of habitat condition analyzed do not reflect the true habitat quality in Coastal Plain streams, the widespread, ongoing nature of human disturbance in this area (very few watersheds have less than 50% agriculture and nutrient loads are typically high) may be a contributing factor (Roth et al. 1999). In low-gradient areas, biological oxygen demand loadings above natural levels may result in dissolved oxygen levels that significantly alter biotic assemblages and obscure relationships with physical habitat.

Conclusions

The 1995–1997 MBSS data set offered a unique opportunity to examine habitat and quantitative fish data through a probability-based sampling program. The geographic strata used in the assessment provided more insights into general fish-habitat relationships among species groups and provided a working framework to test the bioassessment capability of the habitat tolerance index. Findings of this study indicate that relative strength of relation between species-level responses and habitat quality in Maryland can be used to develop reliable biotic response indices for use in state bioassessment programs.

Refinement of a fish IBI in Maryland relies on using accurate and reliable fish assemblage metrics (among others) to assess the extent of degradation within aquatic ecosystems (Gibson et al. 1996). Karr (1987) and Gibson et al. (1996) have shown that as human-induced stress becomes more widespread and complicated, tools should be developed to increase measurement sensitivity to the magnitude of environmental effects (Simon 1999). My study provides background information for the subsequent development of a more refined measure of habitat stress tolerance, which in turn, may lead to a more accurate determination of biological stream health.

The habitat tolerance index presented here appears to have substantial implications for stream assessment. Currently, I am unaware of any established IBIs that specifically incorporate a physical habitat-related metric; the results of this study suggest that existing and new IBIs may be improved by incorporating one or more metrics developed around fish-habitat relationships. Specifically, the best habitat-related metric derived from the index performed as well or better than metrics currently in use for Maryland's current version of a fish IBI.

The application of fish habitat metrics in a statewide, watershed-based management program could lead to the improved assessment of diffuse and nonchemical effects and improve the ability to implement new management strategies for the successful protection and restoration of watersheds. The results from this study may also be useful in identifying fish species that are particularly sensitive to habitat disturbance; this information has implications for land use and other resource management decisions.

The findings of this study support the existing evidence that physical habitat degradation within Maryland's aquatic ecosystems warrants serious concern. Few states effectively monitor for habitat destruction and alteration or effectively integrate existing habitat and biosurvey work into surface water monitoring programs (Rankin 1995). The Ohio EPA (1990) found that stream impairment revealed by biological indicators (such as the IBI) was evident in nearly half of the stream and river segments in which no impairments had been observed, based on chemical indicators (Simon 1999). Nonetheless, some state programs have recognized that threats to the biological integrity of streams are much more extensive than those stemming from water quality threats alone.

The statewide abundance of Maryland's stream fishes appears to be substantially related to habitat. This has important implications for stream restoration and protection approaches, which have historically focused primarily on water quality. Although water quality and physical habitat are clearly linked, it is critical for management efforts aimed at restoring and preserving biological resources within Maryland's aquatic environments to focus attention not only on water quality but on physical habitat disturbance as well.

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